Tropical Cyclone Distribution and Intensity Change

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Grant Number: N00014-02-1-0821
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LONG-TERM GOALS

The long-term goals of this research are to understand the nature of the interactions between tropical cyclones and their larger scale environment, and the impact of these interactions on tropical cyclone intensity and on outbreaks of multiple tropical cyclones.

OBJECTIVES

The primary objectives during the last year have been: (1) To diagnose the effects of vertical wind shear on tropical cyclone structure and (2) To understand the interactions of the Madden-Julian Oscillation (MJO), the monsoon trough, and westward-moving waves in producing outbreaks of tropical cyclones in the western Pacific.

APPROACH

The first objective made use of cloud-to-ground lightning data obtained from the ground-based National Lightning Detection Network (NLDN) and gridded analyses from the European Centre for Medium-Range Weather Forecasting (ECMWF). The lightning data was composited with respect to the tropical cyclone centers, and rotated azimuthally in order to examine its distribution with respect to the vertical wind shear vector or the storm motion vector. All tropical cyclones within range of the NLDN between 1985 and 1999 were included.

The second objective made use of gridded analyses from ECMWF and of outgoing longwave radiation (OLR) data. Both data sets were filtered in time to isolate the slowly-varying background (periods greater than 20 days) from the time scale of waves and tropical cyclones. In addition, a shallow water model was developed to give insight into how the Madden-Julian Oscillation, mixed Rossby-gravity waves, and tropical cyclogenesis are related. The slowly-varying background with an active MJO was simulated by integrating to steady-state with an imposed mass sink. Linear model simulations with small-amplitude disturbances were carried out with this background state assumed fixed. Analytically-defined mixed Rossby gravity wave trains were generated and allowed to interact with the background state.

Looking forward, key individuals beyond the PI are Senior Scientific Programmer David Vollaro, PhD student Anantha Aiyyer, and MS student Kelly Lombardo.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**
4. TITLE AND SUBTITLE **Tropical Cyclone Distribution and Intensity Change**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University at Albany/SUNY,,Department of Earth and Atmospheric Sciences, ES 225,,1400 Washington Avenue,,Albany,,NY, 12222**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The long-term goals of this research are to understand the nature of the interactions between tropical cyclones and their larger scale environment, and the impact of these interactions on tropical cyclone intensity and on outbreaks of multiple tropical cyclones.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

WORK COMPLETED

A paper was published in *Monthly Weather Review* by PhD student Kristen Corbosiero and Molinari entitled "The effects of vertical wind shear on the distribution of convection in tropical cyclones". A second paper is in press in the *Journal of the Atmospheric Sciences* entitled "Relationships between storm motion, vertical wind shear, and convective asymmetries in tropical cyclones".

A paper was published in the *Journal of the Atmospheric Sciences* entitled "Mixed Rossby-gravity waves and western Pacific tropical cyclogenesis. Part I: Synoptic Evolution", by PhD student Michael Dickinson and Molinari.

PhD student Anantha Aiyyer and Molinari submitted a paper to *Journal of the Atmospheric Sciences* entitled "Evolution of mixed Rossby-gravity waves in idealized MJO environments".

M.S. student Kelly Lombardo has studied two significant monsoon gyre events in the northwest Pacific, one in 1988 and one in 1991. Each lasted several weeks and spawned a series of tropical cyclones.

RESULTS

The first paper by Corbosiero and Molinari (2002a) showed the dominant influence of vertical wind shear on the asymmetric structure of convection in tropical cyclones. The maximum convection occurred slightly left of downshear within 100 km of the center, and right of downshear beyond the 100 km radius. The latter signature is the "stationary band complex" of Willoughby et al. (1984), also known as the "rain shield" (Senn and Hiser, 1959). When vertical shear exceeded 5 m s^{-1}, more than 90% of lightning flashes occurred in the downshear half of the circulation in both regions. The paper by Corbosiero and Molinari (2002b) showed that the "storm motion influence" (i.e., asymmetric friction) on convective distribution in hurricanes was identical to that shown previously by many papers in the literature. Nevertheless, it was clearly shown that the asymmetric friction had a much weaker effect than vertical shear. The only reason the motion signature appeared so clearly was that the motion vector and shear vector were closely related: the former was predominantly counterclockwise from the latter, usually by less than 90 degrees. Calculations in the paper indicated that the downshear shift of the upper anticyclone played the most important role in this relationship.

The paper by Dickinson and Molinari (2002) described a remarkable sequence in July 1987, in which a large-amplitude MRG wave packet spawned three consecutive tropical cyclones in nearly the same location (near 10N, 145E). Each cyclone developed in association with a counterclockwise vortex that was initially part of the MRG packet, but then moved northwestward away from the equator. The packet developed under an active MJO, and later dispersed as the MJO moved eastward. The results suggest that tropical wave modes can act as pre-cursor disturbances to tropical cyclones in the western Pacific. The background heating was asymmetric about the equator in the region where the disturbances turned away from the equator. The reason for this turning is still under investigation.

In the monsoon gyre study, we found, as was proposed earlier by Lander (1994), that large monsoon gyres initially developed in regions where upper tropospheric troughs repeatedly penetrated into the subtropics from middle latitudes. In both the 1988 and 1991 cases, however, the gyre moved southward and westward away from the midlatitude forcing and appeared to continue to grow on its own. Ultimately, the convective region with each gyre merged with that of the western end of the traditional monsoon trough. In vertical cross-sections, the gyre appeared as a deep region (up to at least the 300 mb level) of positive relative vorticity, with largest vorticity typically at 850 mb. Active deep convection occurred persistently equatorward from the center of circulation of the gyre. Work is continuing on the mechanisms of formation and motion of the gyres.

The paper by Aiyyer and Molinari (2002) has shown that a background flow arising from a symmetric mass sink about the equator produced growing MRG waves only, but an asymmetric mass sink allowed growth of off-equatorial disturbances with the correct scale to be seedlings for tropical cyclones, even though the initial MRG waves had a 5000 km wavelength. Figure 1 below shows the evolution of the perturbation fields in the presence of a background field associated with an MJO heating that is angled with respect to the equator. The horizontal scale and orientation of the heating resemble those of Dickinson and Molinari (2002). The shaded region in Figure 1 indicates the convergent region in the background state. At hour zero, the only perturbations are analytically derived MRG waves with 5000 km wavelength. After 5 days (panel b), the scale of the MRG waves propagating into the active MJO background decreased, and two smaller centers of positive vorticity developed north of the equator. These moved slowly northwestward during the integration and appeared to decouple from the primary MRG waves, which continued westward along the equator.

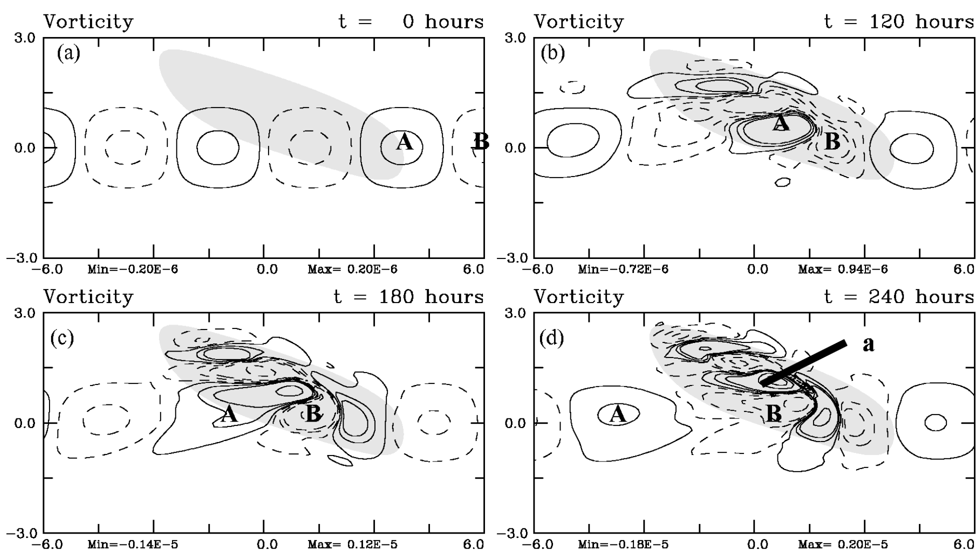

Figure 1. Evolution of perturbation vorticity. The shaded region represents the convergent zone in the background state associated with a similarly-shaped mass sink that is oriented at an angle with the equator, as is often observed.

Figure 2 (next page) contains the height fields at hours 0 and 240 associated with the integration in Figure 1. It is apparent that two low-pressure areas developed off the equator (at about 12°N and 20°N) that were of the appropriate scale (less than or equal to 1000 km) for tropical cyclone seedlings. In nature, these disturbances would produce their own convection via Ekman pumping that could ultimately lead to tropical cyclogenesis. Such off-equatorial disturbances did not develop with symmetric background heating. The results support the suggestion of Dickinson and Molinari (2002) that equatorial modes can be the pre-cursors to tropical cyclogenesis during an active, asymmetric MJO.

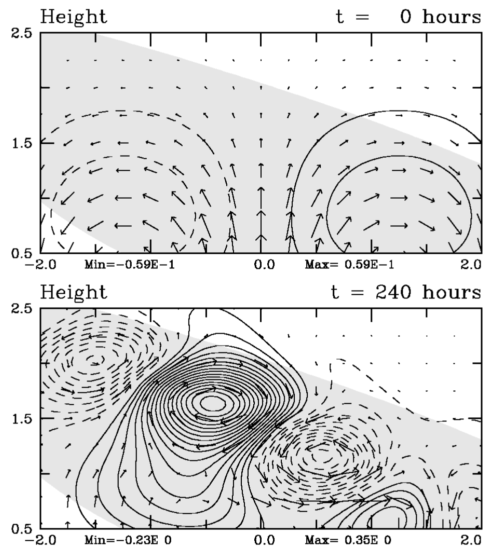

Figure 2. Height and wind fields at hours 0 and 240 for an expanded region of Figure 1.

IMPACT/APPLICATIONS

The Dickinson-Molinari paper provides an additional mechanism by which tropical cyclones can form in the western Pacific. It involves growth within westward moving waves, but the waves are equatorial modes, not traditional "easterly waves". Because these disturbances have very different cloud signatures than the traditional waves, they require a different "synoptic model" to recognize them. We are now working to understand how often this kind of event occurs, and how to identify it in real-time satellite images.

The monsoon gyre studies, when completed, should give some insight into how these disturbances form and move. Although they occur rarely, they are often the locus of multiple tropical cyclone formations and thus are important to understand.

TRANSITIONS

The vertical shear studies are ready for transition. The direction and, to a lesser extent, the magnitude of vertical wind shear can be estimated from satellite pictures using asymmetries in the cloud field. This is beneficial knowledge within storms over open ocean away from observations. It should be noted that this shear signature in convection was known previously, for instance, by Dvorak when he developed his forecast guidance. We have quantified the azimuthal distribution of active convection for two different radial ranges, and have described the interrelationships among vertical shear, storm motion, and convective maxima.

RELATED PROJECTS

We are conducting a study under NSF support of tropical cyclogenesis. We are investigating the structure and dynamics of the hurricane core under NASA support, and the amount and distribution of rainfall in hurricanes after landfall in a project funded jointly with Professor Lance Bosart of my department.

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IN HOUSE/OUT OF HOUSE RATIOS

All of the work is done at the University at Albany, State University of New York.